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Multichannel Demultiplexer/Demodulator Technologies for Future Satellite Communication Systems

William D. Ivancic and James M. Budinger
Lewis Research Center
Cleveland, Ohio

Edward J. Staples
Amerasia Technology, Inc.
Westlake Village, California

Irwin Abramovitz
Westinghouse Electric Corporation
Baltimore, Maryland

Hector A. Courtois
TRW Electronic Systems Group
Redondo Beach, California

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MULTICHANNEL DEMULTIPLEXER/DEMODULATOR TECHNOLOGIES

FOR FUTURE SATELLITE COMMUNICATION SYSTEMS

William D. Ivancic and James M. Budinger, NASA Lewis Research Center—Cleveland, Ohio, U.S.A
Edward J. Staples, Amerasia Technology, Incorporated—Westlake Village, California, U.S.A.
Irwin Abramovitz, Westinghouse Electric Corporation—Baltimore, Maryland, U.S.A.
Hector Courtois, TRW Electronic Systems Group—Redondo Beach, California, U.S.A.

Abstract

NASA Lewis Research Center's Space Electronics Division supports ongoing research in advanced satellite communication architectures, onboard processing, and technology development. Recent studies indicate that meshed VSAT (very small aperture terminal) satellite communication networks utilizing FDMA (frequency-division, multiple-access) uplinks and TDM (time-division-multiplexed) downlinks are required to meet future communication needs. One of the critical advancements in such a satellite communication network is the multichannel demultiplexer/demodulator (MCDD). This paper describes the progress made in MCDD development using either acousto-optical, optical, or digital technologies.

1. INTRODUCTION

In the late 1970's NASA sponsored a number of system studies to investigate future satellite communication systems. Results indicated that the architecture of the future will include time-division, multiple-access/time-division-multiplexed (TDMA/TDM) uplinks and downlinks. These system studies provided the framework for the development of the Advanced Communication Technology Satellite (ACTS).

The available technology in the early 1980's did not allow for a multichannel demultiplexer/demodulator (MCDD) to be implemented with reasonable size, weight, and power requirements. For this reason, a TDMA uplink was selected over the frequency-division, multiple-access (FDMA) uplink. Also, during the early 1980's, the blossoming of fiberoptic technology changed the overall communication marketing structure. Fiber is now used for most moderately high and high data rate (tens to hundreds of megabits per second) point-to-point traffic.

Because the telecommunication system scenarios that are the basis for ACTS have changed dramatically, NASA recently sponsored new system studies to identify future satellite architectures and to develop corresponding technologies [1]-[3]. These studies indicate that an FDMA/TDM architecture offers a satellite communication system that is economically competitive with current and future terrestrial communication links.

As presently envisioned, future architecture will consist of multiple uplinks, each with thousands of very small aperture terminals (VSAT) to access the satellite in an FDM (frequency-division-multiplexed) mode; a processing and routing satellite; and multiple high-burst-rate TDM downlink spot and scanning beams (Figure 1). This architecture is suitable for a satellite communication system that is cost competitive with terrestrial communication networks by optimizing the cost and complexity onboard the satellite in order to minimize the cost of the ground terminals [4]-[6].

The MCDD has been recognized as a critical subsystem which needs to be developed for an FDMA/TDM architecture. Acousto-optical, optical, and digital signal processing technologies have been identified as options to implement an MCDD. NASA is investigating each of these approaches through contacts, grants, and in-house research.

This paper describes the advancements made in MCDD research under various NASA contracts. In addition, a proposed commercial experiment, which would use one of the MCDD's under development, is described briefly.

2. REQUIREMENTS

For a meshed VSAT communication system the MCDD must be capable of simultaneously demultiplexing thousands of narrowband channels and hundreds of wideband channels. In this system the narrowband channels are associated with single-channel-per-carrier systems and must be compatible with the emerging integrated services digital network (ISDN) standards. Therefore, the narrowband channels must accommodate 64-kbps data and the wideband channels, also based on ISDN standards, must have a minimum of twenty-four 64-kbps channels. The MCDD must accommodate a maximum dynamic range of 8 dB between individual input channels with an overall design applicable to space-qualified hardware implementation. The modulation scheme has not been specified to allow the contractors to trade off bandwidth and power efficiency. Contractors have also been given free reign to trade off implementation complexity with communication system constraints, including network synchronization and the distribution of narrowband and wideband channels. Any communication system constraint must be fully justified, and a method for working within such constraints presented.

For the proof-of-concept (POC) model MCDD, only those items deemed essential to the MCDD concept must be implemented. Therefore some contractors proposed implementing the full MCDD while others concentrated on the demultiplexing function, although the entire MCDD is required to be characterized. The POC design has to be expandable for demultiplexing and demodulating thousands of narrowband users; however, it has to demonstrate demultiplexing and demodulation of only four narrowband and two wideband channels.

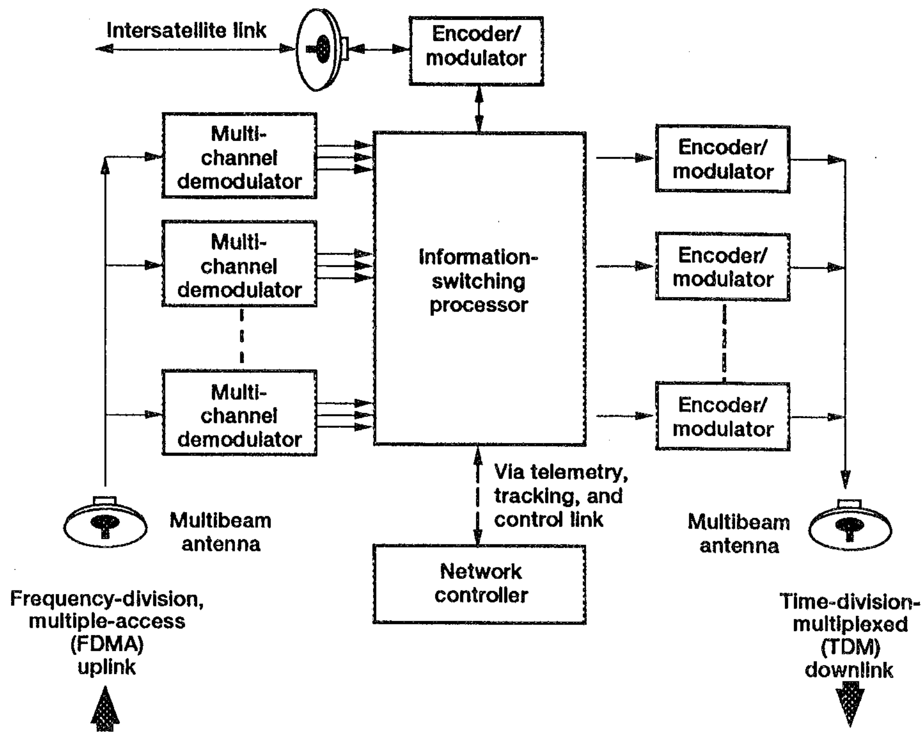

FIGURE 1. INFORMATION-SWITCHING PROCESSOR

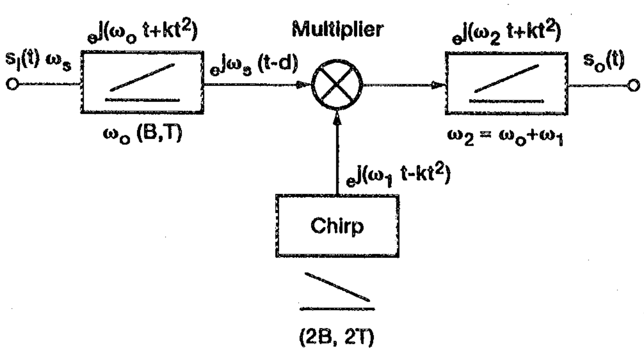

FIGURE 2. CONVOLVE-MULTIPLY-CONVOLVE (CMC) CHIRP TRANSFORM

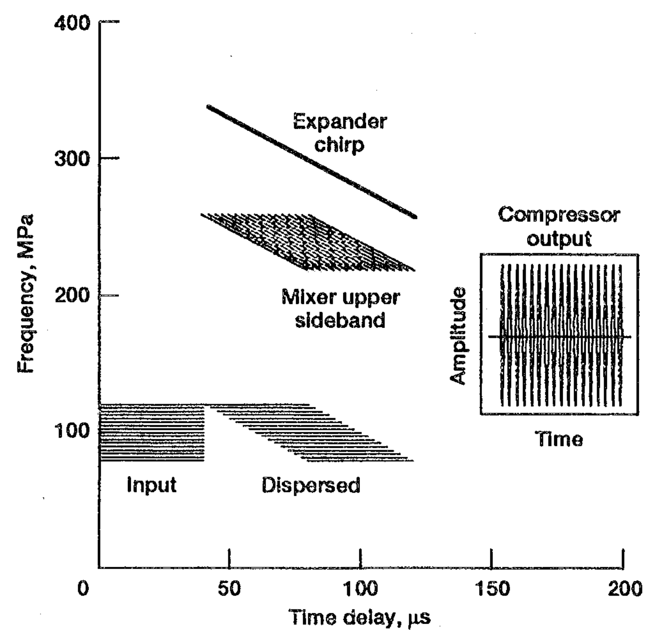

FIGURE 3. FREQUENCY VS TIME SIGNAL FLOW IN A CONVOLVE-MULTIPLY-CONVOLVE (CMC) CHIRP-TRANSFORM-PROCESSOR

3. ACOUSTO-OPTICAL APPROACH

Amerasia Technology Incorporated is presently under contract to NASA (NAS3-25682) to develop a proof-of-concept (POC) multichannel demultiplexer/ demodulator (MCDD). Their objective is to demonstrate demultiplexing of multiple low-data rate users from a composite radiofrequency (RF) signal while preserving the modulation content. The multichannel demodulator is implemented as a convolve-multiply-convolve (CMC) chirp-transform-processor using surface acoustic wave (SAW) reflective array compressors (RAC). For this demonstration, a time-shared quadrature phase-shift keying (QPSK) demodulator is used [7]-[9].

The basic operation of the CMC processor is depicted in Figure 2. The first SAW RAC has characteristics that delay the high-frequency signals less than the lower frequency signals. The individual narrowband channels that make up the composite RF signal pass through the first SAW RAC and are separated in time. These signals are then multiplied by a frequency expander which repetitively sweeps downward at twice the bandwidth of the composite signal and over a period of 4 times the modulation symbol rate. At the mixer output is a series of down chirps corresponding to each narrowband channel. The compressor is implemented using another SAW RAC with identical time-bandwidth and slope characteristics to the input RAC. The output of the compressor RAC consists of compressed RF pulses spaced in time. The overall effect is that each input carrier frequency is transformed into the time domain on a common frequency (Figure 3).

For a communication link, the CMC processor must be designed so that intersymbol interference is minimized. This can be accomplished be either designing filtering into the SAW RAC devices or incorporating the filtering into the chirp generator. Since the chirp generator functions as an arbitrary waveform generator, it is easy to incorporate the filtering here.

In order to take advantage of the CMC processor in communication systems, two problems have to be overcome. First, there is a notable phase shift at the output of the CMC processor relative to minor changes in input frequency of a given narrowband channel. In order to obtain coherent demodulation of phase-modulated signals, the carrier phase-tracking circuit has to account for the phase shift introduced by the CMC processor. Second, there is a shift in the output time of a given channel caused by the expansion of the SAW devices with respect to the change in temperature. Fortunately, this time shift is common to all input frequencies. An automatic tracking circuit can be used which monitors a single channel for temperature and timing variations and makes the necessary timing adjustments for all channels.

In the future, the CMC processor could be improved by replacing the conventional RAC with a hyperbolic inline reflective array compressor (HIRAC) (Figure 4). The HIRAC uses hyperbolically shaped transducers and a herringbone RAC configuration which has a number of advantages over conventional SAW techniques. This device has large time-bandwidth products, low-insertion loss, flat frequency response, and the capability to operate over a wide range of temperatures. Compared to conventional RAC's, the HIRAC is relatively easy to fabricate and, therefore, potentially low cost.

The CMC processor has these advantages: (1) the technology is rather simple, robust, and proven in radar applications and (2) the output is situated at a common carrier and presented in a TDM format that can be demodulated by a single circuit.

There are two limitations with this type of channelizer. First, it requires that the network be synchronized to within a fraction of a bit time. Second, the MCD only operates on discrete, equally spaced channels; therefore, separate channelizers have to be built for narrowband and wideband channels.

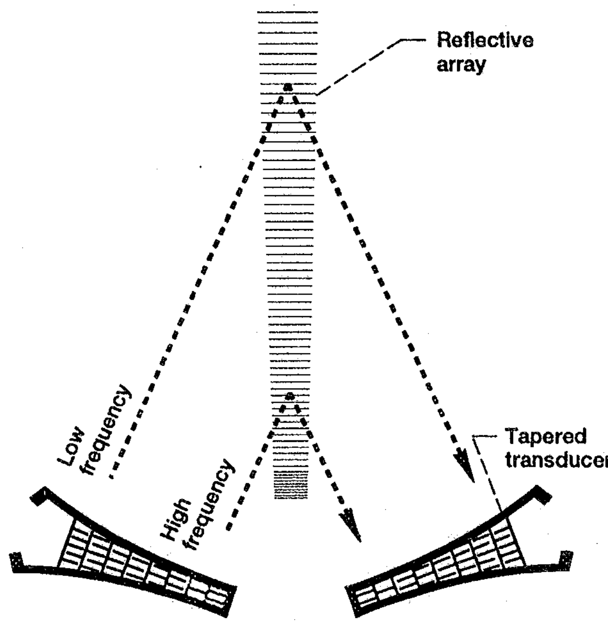

FIGURE 4. SINGLE-BOUNCE DISPERSIVE FILTER GEOMETRY

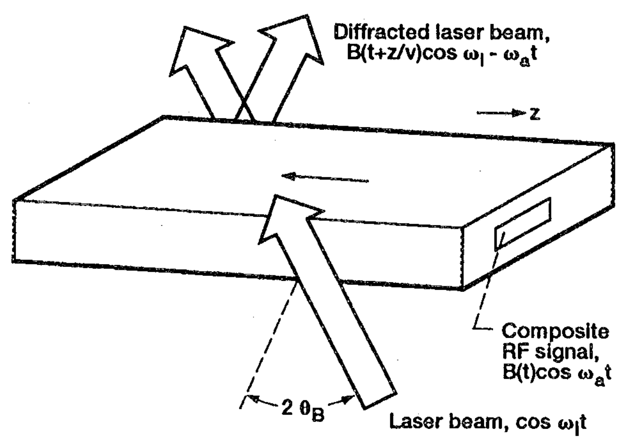

FIGURE 5. BRAGG INTERACTION GENERATES A DIFFRACTED BEAM AT AN ANGLE PROPORTIONAL TO THE ACOUSTIC SIGNAL'S FREQUENCY. THIS BEAM IS MODULATED IN AMPLITUDE, FREQUENCY, AND PHASE BY THE ULTRASONIC-ACOUSTIC COMPRESSION WAVE.

4. OPTICAL APPROACH

Westinghouse Electric Corporation's Communications Division is presently under contract with NASA (NAS3-25865) to develop a POC multichannel demultiplexer (MCD) which demonstrates the capability of demultiplexing 1000 low-data rate FDMA uplinks. The multichannel demultiplexer is implemented as an acousto-optic RF spectrum analyzer utilizing heterodyne detection with a modulated reference. Demodulation is performed using a commercial demodulator. A photodetector is placed at the focal point of the channel of interest. The signal is then fed into the commercial demodulator which fully characterizes the effect of the optical demultiplexer on a modulated signal such as OQPSK (offset quadrature phase-shift keying).

The acousto-optic spectrum analyzer is based on the Bragg interaction between light and sound in a crystaline material (Figure 5). An ultrasonic compression wave is impressed on the crystal. A portion of a laser beam passing through the Bragg cell will be diffracted at an angle proportional to the RF signal applied to the acoustic transducer. The diffracted beam is modulated in amplitude, frequency, and phase by the Bragg interaction, and the intensity is proportional to the power of the applied RF signal. For heterodyne detection with a modulated reference (Figure 6), the output of the signal at the photodetector occurs at a common intermediate frequency (IF) and is proportional to the amplitude of the communication signal. Thus, the MCD performs both the demultiplexing and the downconversion of the composite RF signal [10].

The acousto-optic spectrum analyzer has many advantages over other demultiplexing approaches. The system is very reliable because the majority of the components are passive. The cost for the components is minimal. The system has extremely high-performance characteristics: greater than 40 MHz of bandwidth corresponding to greater than one thousand 64-kbps channels at 1.6 bps/Hz efficiency using OQPSK modulation; a dynamic range in excess of 80 dB; no quantization noise (because there is no analog-to-digital converter required); no electromagnetic interference; and inherently radiation-hard optical components. A full-scale system consisting of both narrowband and wideband MCDD and incorporating the optical detector and demodulation circuitry on a single chip ASIC (application-specific integrated circuit) is expected to require only 20 to 30 W of power and 150 in.^{3}. The MCD is modulation-independent and does not require the synchronization of the transmitting portion of the ground terminals to the satellite timing. In addition, the MCD can be easily characterized, independent of the demodulator, using conventional RF techniques. Characteristics include AM transfer, bandpass, adjacent channel rejection, spurious signals (caused by the demultiplexer), and dynamic range.

The only major limitation to using the acousto-optic spectrum analyzer for the MCD is that separate channelizers have to be built for narrowband and wideband channels. Techniques have been developed that overcome the temperature stability and alignment problems associated with the acousto-optic spectrum analyzer.

Future work includes optimizing the modulation scheme for better system performance and integrating the optical detector array and demodulation circuitry on a single chip ASIC.

5. DIGITAL MCDD

TRW Electronic Systems Group is presently under contract with NASA (NAS3-25866) to develop a POC MCDD using

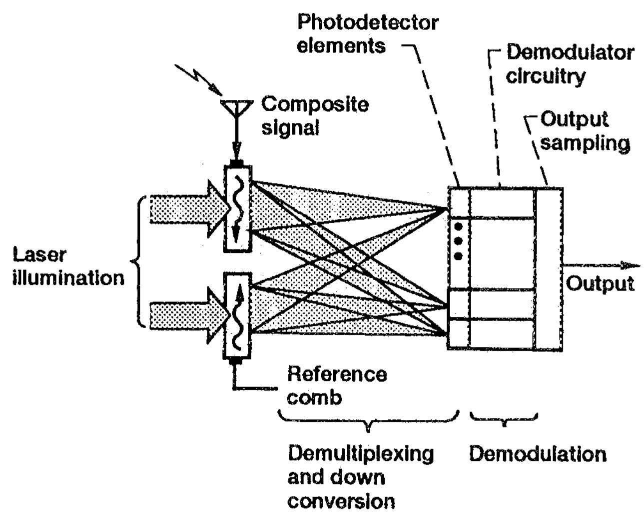

FIGURE 6. MCDD POC MODEL FOR HETERODYNE DETECTION WITH A MODULATED REFERENCE

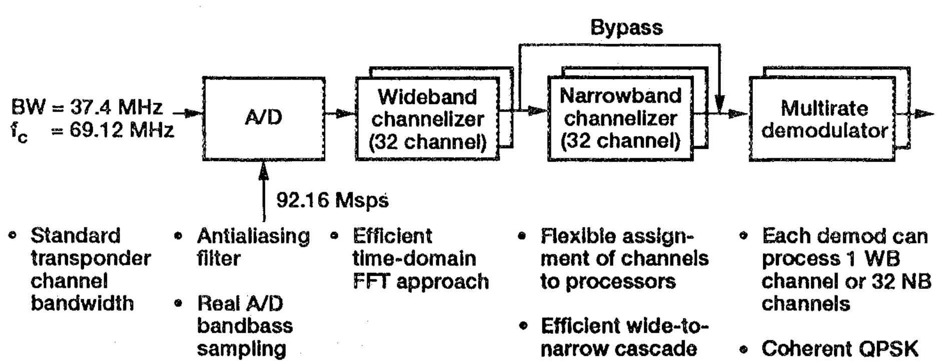

FIGURE 7. MCDD BLOCK DIAGRAM

advanced digital technologies. This POC model demonstrates the capability of demultiplexing and demodulating multiple low-to-medium data rate FDMA uplinks with expansion potential for demultiplexing and demodulating hundreds to thousands of narrowband uplinks [11]-[12]. The TRW approach uses base-band sampling followed by successive wideband and narrow-band channelizers with each channelizer feeding into a multirate, time-shared demodulator (Figure 7). A full-scale MCDD consists of an 8-bit A/D (analog-to-digital) sampling at 92.16 MHz, 4 wideband channel-izers capable of demultiplexing 8 wideband channels, 32 narrowband channelizers capable of demultiplexing 1 wideband signal into 32 narrowband channels, and 32 multi-rate demodulators. The POC model consists of an 8-bit A/D sampling at 23.04 MHz, 1 wideband channelizer, 16 narrowband channelizers, and 3 multirate demodulators (Figure 8).

For a 40-MHz transponder, the MCDD is capable of demultiplexing and demodulating 26 wideband and 728 narrow-band channels. The modulation format is filtered OQPSK such that a 64-kbps channel resides in a 45-kHz bandwidth and a 2.048-MHz channel resides in a 1.44-MHz bandwidth. Three wideband channel's worth of guardband are required on either side of the 40-MHz transponder bandwidth leaving 37.5 MHz of usable bandwidth. Two narrowband channel's worth of guard-band are required on either side of the 1.44-MHz wideband channel leaving 1.26 MHz of usable bandwidth (Figure 9). Note however, these guardband channels are demodulated and could be used with reduced performance.

The demultiplexing function utilizes polyphase filtering techniques. TRW's channelizer is implemented as a time-domain fast Fourier transform (FFT) in a wideband-to-narrow-band cascade. The algorithm processes the data in the time domain by windowing and presuming and is followed by a single FFT to heterodyne the signal. This technique optimizes the use of hardware to realize a parallel bank of filters (Figure 10). The windowing and presuming functions are accomplished through an ASIC because it is repeated throughout the design and is useful in many other applications.

The multirate, time-shared demodulator (Figure 11) is configured to perform as a normal demodulator with some exceptions. A resampling filter is required as an interface between the demultiplexing and demodulation functions. Register banks are located within each loop to store the data samples that correspond to 32 narrowband channels embedded

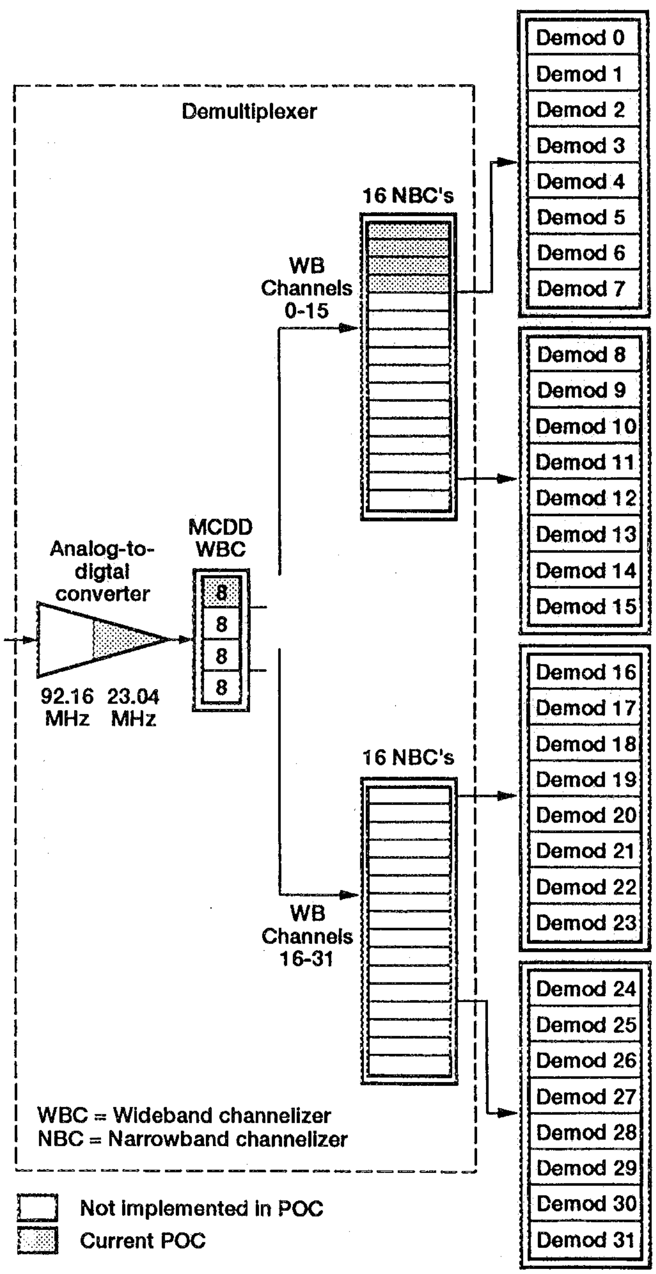

FIGURE 8. MCDD POC MODEL BLOCK DIAGRAM

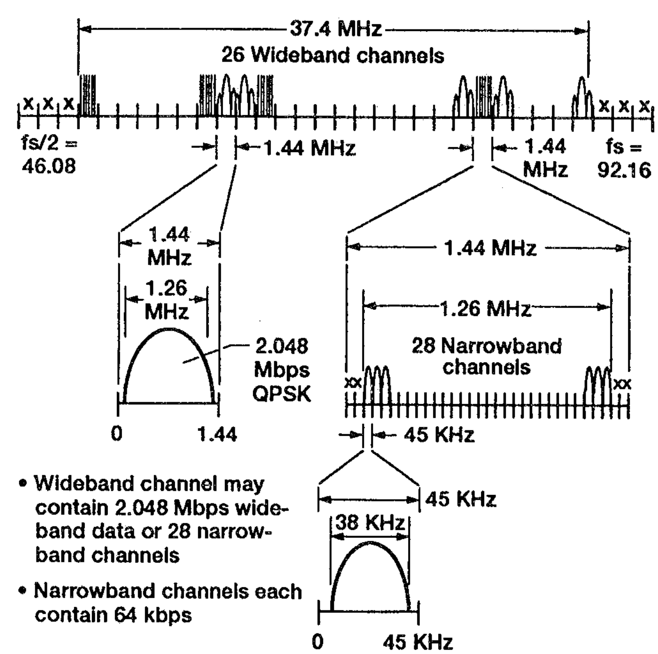

FIGURE 9. MCDD FREQUENCY PLAN

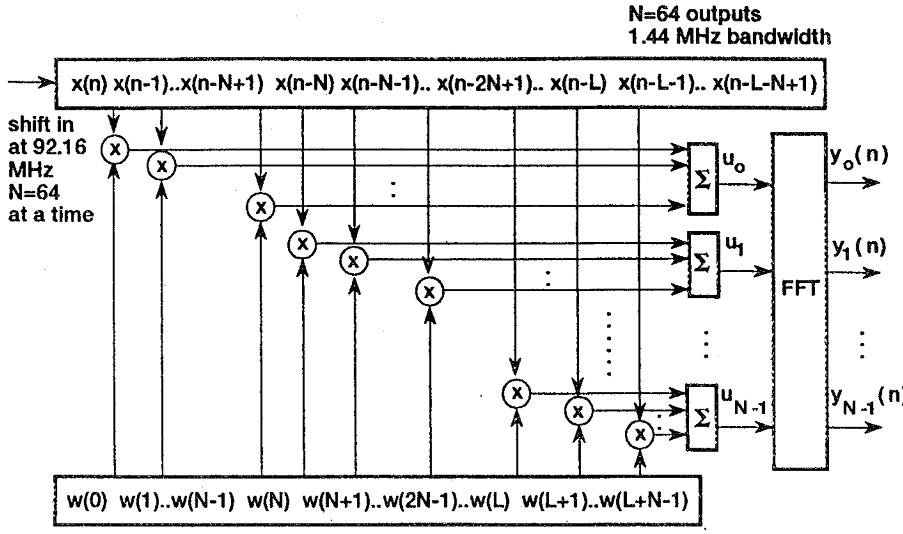

FIGURE 10. TIME-DOMAIN FFT CHANNELIZER

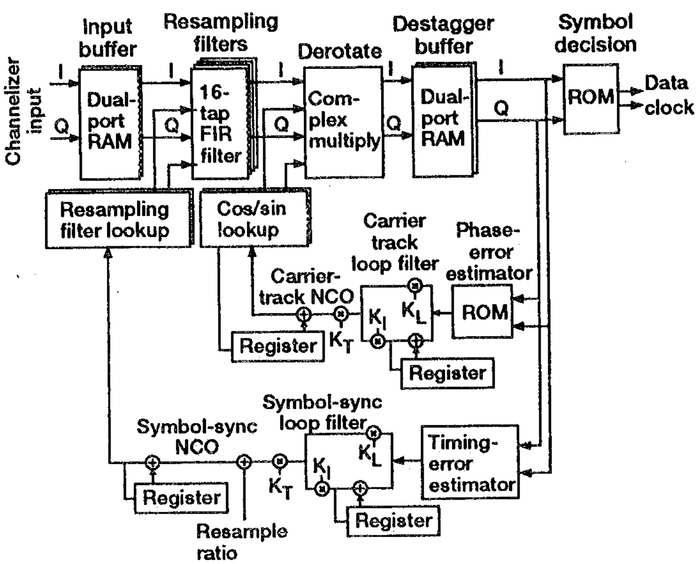

FIGURE 11. DETAILED MULTIRATE DEMODULATOR

in the wideband channel. The carrier-tracking loop, the symbol-synchronization loops, and the derotation, destagger, and symbol-detection circuitry are designed precisely as an independent demodulator except for the time-shared functionality. The resampling filter performs pulse-shaping of the baseband data and interpolation. Data at 1.44 Msamples/sec from the demultiplexer is resampled into either 1.024 Msymbols/sec for the wideband channels or 32 ksymbols/sec for the narrowband channels. This interpolation causes the demodulator to expel the data in a nonuniform rate so that sometimes two samples from the filter are valid and sometimes only one sample is valid.

There are a number of advantages to the digitally implemented MCDD. First, only one MCDD is required for both the wideband and narrowband channels. In fact, nothing in the design precludes cascading a third or fourth channelizer to the demultiplexer, although practical networking and switching scenarios do not require this. Second, the demultiplexing is independent of the demodulation. Third, the modulation format can be altered simply by changing the lookup tables in the derotation circuitry of the demodulator. Fourth, the demodulator can handle asynchronous users since each channel maintains its own symbol, carrier, and phase offsets. Fifth, there exists the potential, in 10 to 20 years, to condense the design down to a few-chip solution using custom VLSI (very large-scale integrated) circuit design and multichip module packaging.

There are three identifiable drawbacks to this application. First, an MCDD with 40-MHz bandwidth capability requires an 8-bit, 92-Msample/sec A/D with good linearity to 40 MHz. Second, the irregular data from the demodulator requires some additional first-in, first-out (FIFO) buffering at the interface demodulator output. Third, the digital approach is not yet considered robust and fault-tolerant because of the overall complexity of the system. The FFT's susceptibility to single event upsets and catastrophic faults is of particular concern.

Future work in this area will improve the packaging and will address the many fault-tolerant issues pertinent to both the demultiplexing and demodulation functions.

6. PROPOSED COMMERCIAL EXPERIMENT

In order to insert new technologies into real applications much quicker than would otherwise be possible, a commercial experiment using one of the MCDD concepts currently under development has been proposed. A small experimental payload would be placed on a commercial satellite. The experimental package would use the existing receivers and transmitter and would be designed so that the transponder channel could either be used in a conventional manner or as an FDMA/TDM or FDMA/FDM system with limited switching and routing capability

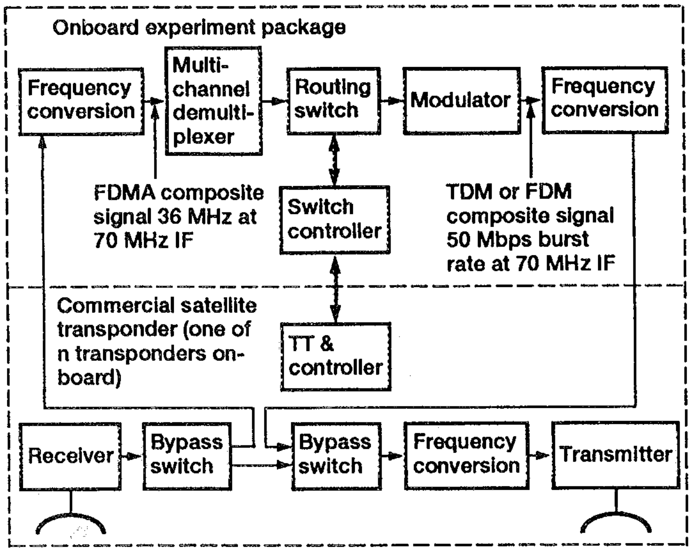

FIGURE 12. PROPOSED COMMERCIAL EXPERIMENT

(Figure 12). Link analysis has verified that such a system could operate at C-, Ku-, or Ka-band. In exchange for carrying this experimental package, the commercial carrier would be allowed to market the new capabilities once the experimental period is completed.

7. CONCLUSION

NASA Lewis Research Center has an ongoing program in onboard processing technology development. The multichannel demultiplexer/demodulator is a major element of this program and is being heavily investigated through in-house efforts, contracts, and grants. The present MCDD contracts are scheduled for completion in mid- to late 1992. At this point, an assessment will be made to determine the approach that is best suited to NASA's future program requirements. At the moment, all technologies (acousto-optical, optical, and digital) have very good potential, each with advantages and disadvantages. The digital approach is attractive for circuit-switch applications because only one MCDD is required for both wideband and narrowband signals. The optical approach is promising in a multifrequency TDMA or multifrequency CDMA (code-division multiple-access) network because of the reliability, size, weight, and power characteristics. However, only after complete MCDD characterization can we determine which technology will be best for a specific application. Perhaps each has a place depending on the particular application.

8. REFERENCES

1. Price, K.; Jorasch, R.; and Wiskerchen, M.: Data Distribution Satellite. (SSL-TR00722, Space Systems/Loral; NASA Contract NAS3-25092), NASA CR-187066, 1991.

2. Bruno, R.; and Welti, G.: A Satellite System Concept for Fully-Meshed VSAT Networks. Stanford Telecommunications, Apr. 1990.

3. Horstein, M.; and Hadinger, P.: Advanced Space Communication Architecture Study. (TRW Electronic Systems Group; NASA Contract NAS3-24743), NASA CR-179592, 1987.

4. Ivancic, W.D.; and Shalkhauser, M.J.: Destination Directed Packet Switch Architecture for a 30/20 GHz FDMA/TDM Geostationary Communication Satellite Network. Space Communications Technology Conference Onboard Processing and Switching, NASA CP-3132, 1991, pp. 9-24.

5. Ivancic, W.D.: Circuit Switch Architecture for a 30/20 GHz FDMA/TDM Geostationary Communication Satellite Network. Prepared for presentation at the 13th AIAA International Satellite Communication Conference, March 1992.

6. Campanella, S.J.: Communication Satellites: Orbiting into the 90's. IEEE Spectrum, Vol. 27, no. 8, 1990, pp. 49-52.

7. Staples, E.J.: Multi-User Satellite Communications System Using an Innovative Compressive Receiver. NASA Advanced Modulation and Coding Technology Conference, 1989.

8. Staples, E.J.: Advanced Satellite Communication System SBIR Phase I Final Report. Amerasia Technol., NASA Contract NAS3-25617, 1990.

9. Lie, Y.S.; and Ching, M.: Application of Convolve-Multiply-Convolve SAW Processor for Satellite Communications. Space Communications Technology Conference Onboard Processing and Switching, NASA CP-3132, 1991, pp. 199-205.

10. Fargnoli, J.; and Riddle, L.: Optimization of an Optically Implemented On-Board FDMA Demultiplexer. Space Communications Technology Conference Onboard Processing and Switching, NASA CP-3132, 1991, pp. 179-189.

11. Lee, D.D.; and Woo, K.T.: Design, Modeling, and Analysis of a Multi-Channel Demultiplexer/Demodulator. Space Communications Technology Conference Onboard Processing and Switching, NASA CP-3132, 1991, pp. 191-197.

12. Sherry, M.A.; and Caso, G.S.: Multi-Rate Demodulator Architecture. Space Communications Technology Conference Onboard Processing and Switching, NASA CP-3132, 1991, pp. 191-197.

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William D. Ivancic, James M. Budinger, Edward J. Staples, Irwin Abramovitz, and Hector A. Courtois

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